The Effects of Sediment Deposition on Insect Populations and Production in a Northern Indiana Stream

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Abstract
In 1986 the St. Joseph County, Indiana, Drainage Board began conducting routine maintenance operations in and along Juday Creek, a third-order tributary of the St. Joseph River. These activities, which include debris and snag removal from stream channels, have led to a large increase in sediment deposition into the lower reaches of the stream. Monthly benthic invertebrate samples were collected from June 1989 to June 1990 from a riffle area in Juday Creek and insect densities and secondary production rates during this time were compared to those from a previous study at the same site in 1981-82. Invertebrate density and production rate responses varied based on functional feeding group. Among filter-feeders, two species showed significantly lower mean annual densities in 1989-90 compared to 1981-82, two species showed significantly lower densities during several months in 1989-90 versus corresponding months in 1981-82, and only one species (Hydropsyche morosa) showed significantly greater density in 1981-82. Among collector-gatherers, mean annual densities were significantly higher for five of six species collected in 1989-90. Shredders showed mixed responses, with two species having significantly higher mean annual densities in 1981-82, and one species, Taeniopteryx nivalis, having higher densities in 1989-90. While production rates of three of the five species for which production rates were calculated increased in 1989-90, the net effect of the increased sediment deposition was a reduction in the combined production rates of the five species from 2765.1 mg/m^2/year in 1981-82 to 653.8 mg/m^2/year in 1989-90.

Key Words: sediment, water quality, secondary production, functional feeding group, filter-feeders, collector-gatherers, shredders, benthic macroinvertebrates

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Introduction
The effects of anthropogenic disturbances such as clear-cut logging, modification of riparian vegetation, and changes in land-use practices on streams and aquatic organisms are well documented (Dance and Hynes 1980, Swanson et al. 1982, Ward 1984). Physical and chemical attributes of streams affected by these activities include light penetration (McIntire and Colby 1978), water temperature (Hall and Lantz 1969, Holtby 1988), nutrient concentrations (Chauvet and Decamps 1989), and inputs of woody debris and sediments (Bryant 1983, Swanson et al. 1987). Such changes have been shown to affect algae (Minshall 1978), macrophytes (Hynes 1970), invertebrates (Newbold et al. 1980), fish (Thedinga et al. 1989, Ward and Stanford 1989) and other vertebrates (Hawkins et al. 1983, Spencer et al. 1991). However, impacts associated with more subtle or routine activities such as removal of snags and woody debris from streams are less understood. Because such operations likely represent common and widespread management practices in the midwestern United States, quantifying their impact on the biota is essential.

In 1986, the St. Joseph County (Indiana) Drainage Board began to perform maintenance operations in and along Juday Creek, a third-order tributary of the St. Joseph River. Included in these activities are removal of snags, debris, and trees that block water flow and that might result in flooding or pooling along the stream. Coincident with these practices in Juday Creek has been a large increase in sediment transport and subsequent deposition in downstream locations. Because data on insect production rates and populations were collected from this stream in 1981-82 (Schwenneker 1985) and 1985-86 (M.B. Berg pers. comm.), prior to drainage board activities, we had an opportunity to document changes in population densities and production rates of stream benthos that may have resulted from stream maintenance operations. Our objectives were to consider 1) the effects of increased sediment deposition on benthic macroinvertebrate populations; 2) whether changes in population densities were reflected by changes in invertebrate secondary production rates; and 3) the implications of these results for predicting invertebrate responses to sediment deposition.

Study Site

This study was conducted in a riffle area of the creek (41°43'N, 86°16'W, elevation = 206m) on land owned and maintained by the St. Joseph Co. Chapter of the Izaak Walton League of America. Juday Creek is important from a conservation perspective because it is one of only a few streams in Indiana known to support breeding trout populations. The upper segment flows through flat, agricultural land, and then makes its way through primarily residential areas. The lower segment, which includes the study location, flows through natural, deciduous woodlands and has a gradient of 1.3%. The site is heavily shaded from the late spring through the early fall, and the substrate is a mixture of sand, gravel, and cobble. Some of the physical and chemical data collected at this site in 1981-82 and 1989-90 are summarized in Table 1.

A silt trap is located approximately 100 m upstream from the site. It was built to protect the lower segment of Juday Creek from excessive sediment deposition. Prior to drainage board operations, approximately 18 yd^3 of sediment were removed from the silt trap every 1.5-2 years. Since 1988 the silt trap has been dredged once a year. In 1989, approximately 90 yd^3 of sediment were removed from the trap (J. Moore, pers. comm.). However, during the 1989-90 sampling period, the trap was completely filled after 4 months. Therefore, it provided little or no protection to the lower part of the stream for 8 months. During March and early April 1990, a large pulse of sediment entered the study area, resulting in extensive coverage of the gravel and cobble substrate with sand. This pulse was apparently a result of an unusually high number of stream maintenance activities during this period compared to previous years.

Materials and Methods

Benthic samples were collected monthly for a period of thirteen months during the course of two separate studies. The first was from September 1981 to September 1982 (Schwenneker 1985) and the second from June 1989 to June 1990. In both studies, ten random benthic bottom samples were collected each month from the riffle using a 0.09 m^2 Hess sampler with a mesh size of 333 μm. Because of extremely high water levels, samples could not be collected in January and March of 1982, and these two months were omitted from comparisons between years. Samples were preserved in 80% ethanol and transported back to the laboratory for processing and analysis.

In the laboratory, invertebrates were sorted from the substrate using sugar flotation (Anderson 1959) and then identified to species and instar or size class. Instar determinations were based on head capsule width, except for stoneflies and mayflies. These organisms were divided into size classes based on body length from the front of the head to the base of the cerci. Population densities were recorded for the most abundant species (excluding chironomids), and each was assigned to a functional feeding group (Merritt and Cummins 1984). Mean annual densities were compared between years using a repeated measures analysis of variance on log transformed data

Table 1. Comparison of physical and chemical characteristics of Juday Creek in 1981-82 and 1989-90.

	1981-82	1989-90
Temperature (°C)	2.5-17.0	1.5-20.5
Current Velocity (m/s)	0.3-0.5	0.4-0.65
Depth (cm)	20-30	20-40
Alkalinity (mg/l $CaCO_3$)	150	182
Nitrate (mg/l-N)	1.0	1.5-1.7
Orthophosphate (mg/l)	0.13	0.16
Conductivity (μmho/cm)	600	610-680

In addition, densities of each species were compared month by month between years (i.e., January 1982 versus January 1990) using a one-way ANOVA. Production rates were calculated for all species in the 1981-82 study, and for five species in the 1989-90 study, including Hydropsyche sparna Ross, Hydropsyche betteni Ross, Optioservus fastiditus (LeConte), Baetis vagans McDunnough, and Taeniopteryx nivalis (Fitch). Dry weights for each instar or size class of these organisms were obtained by drying at 70°C for 48 hours. Production rates were measured using either the instantaneous growth method for those species with distinguishable cohorts, or the size-frequency method for those with cohorts that could not be distinguished. Instantaneous growth calculations were made from computer programs developed by Schwenneker (1985) and Berg (1989). Size-frequency production calculations were made using the Aquatic Ecology-PC software package (Ekblad 1986). Because early instars often are inefficiently sampled, apparent increases in population densities are sometimes seen during cohort development. For production rate calculations, densities were back-calculated using the catch-curve method of Waters and Crawford (1973). The result of this correction was that if densities were lower at sampling time T-1 than at time T, densities at time T-1 were set equal to those at time T. Given the typical log-type decline exhibited by stream invertebrates, this correction represents a conservative estimate of densities (Schwenneker 1985).

Results

Population responses of individual species to sedimentation varied depending on functional feeding group. Among the six species of filter-feeders, four had lower mean annual densities in 1989-90, although only two of these differences were statistically significant (Table 2). Hydropsyche sparna and Chimarra obscura (Walker) showed the most dramatic density reductions in 1989-90 (over 80% and 95% respectively). Mean annual densities of Hydropsyche betteni and Cheumatopsyche petiti (Banks) were not significantly different between years, but each did show significant density differences in eight of the ten monthly comparisons (Fig. 1). During six of these months, H. betteni showed higher densities in 1981-82 compared to 1989-90, and C. petiti had significantly higher densities in 1981-82 during five months. Hydropsyche morosa (Ross) mean annual density was significantly higher in 1989-90 compared to 1981-82, and Simulium sp. had similar densities between years. All six filter-feeders had lower densities, four of which were significant ($p<.05$), in April and May of 1990 versus 1982.

The reduction in secondary production rates of filter-feeders in 1989-90 was much more pronounced than changes in population densities (Fig. 2). The production rate of H. sparna dropped more than 90% in 1989-90 from the 1981-82 rate. From 1981-82 to 1989-90, the production rate of H. betteni declined by more than 50%, while mean annual density was reduced about 30% in 1989-90.

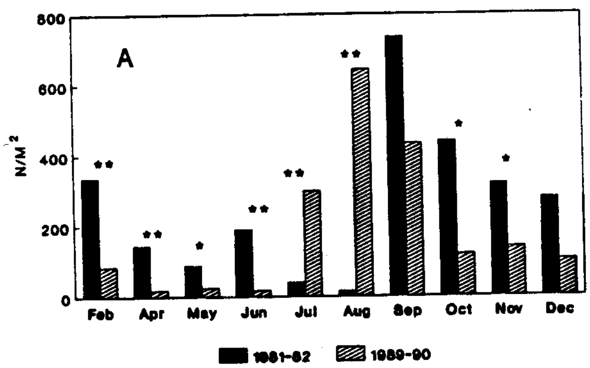
Population densities of collector-gatherers showed different responses to the increased sediment deposition than the of filter-feeders. Five of the six species of collector-gatherers showed significantly greater mean annual densities in 1989-90 compared to 1981-82

Table 2. Mean annual densities (N/M^2) and *p* values of individual taxa in 1981-82 and 1989-90. * = $p < 0.05$; ** = $p < 0.01$.

	1981-82 Mean (1 SE)	1989-90 Mean (1 SE)	p
Filter-feeders			
Cheumatopsyche petiti	223.2 (18.2)	194.3 (30.6)	0.270
Chimarra obscura	44.2 (4.0)	2.2 (0.4)	**0.001
Hydropsyche betteni	258.8 (23.0)	187.9 (24.2)	0.097
Hydropsyche morosa	26.3 (2.4)	113.6 (18.9)	**0.001
Hydropsyche sparna	1648.7 (136.9)	293.7 (35.6)	**0.001
Simulium sp.	45.9 (5.4)	47.3 (13.4)	0.376
Collector-gatherers			
Antocha sp.	43.9 (3.3)	57.6 (5.2)	**0.001
Baetis vagans	17.3 (2.4)	32.7 (12.0)	**0.001
Macronychus glabratus	----------	34.0 (4.5)	-------
Optioservus fastiditus	22.1 (1.7)	144.0 (12.8)	**0.001
Stenelmis crenata	3.9 (0.7)	155.1 (13.0)	**0.001
Stenonema spp.	56.5 (5.1)	91.3 (10.7)	**0.001
Shredders			
Amphinemura delosa	66.6 (8.6)	3.4 (0.7)	**0.001
Taeniopteryx nivalis	6.5 (1.4)	38.8 (8.1)	**0.001
Tipula abdominalis	3.3 (0.5)	1.3 (0.3)	**0.001

(Table 2). The elmid beetle larvae Optioservus fastiditus and Stenelmis crenata (Say) had the largest increases in mean annual densities between years (650% and almost 4000%, respectively). Macronychus glabratus (Say) was collected so rarely in 1981-82 that its density was not reported by Schwenneker (1985). Therefore, we could not compare densities between years, although densities were clearly greater in 1989-90. Densities of some species of collector-gatherers dropped in April and May of 1990, although some declines could be explained partly by life history characteristics.

We compared secondary production rates between years for two species of collector-gatherers, Optioservus fastiditus and Baetis vagans. Production rates showed changes



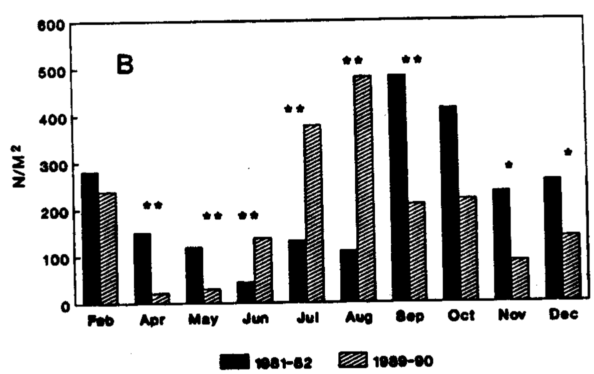


Figure 1. (A) Mean densities (N/M²) by month for Hydropsyche betteni in 1981-82 and 1989-90. (B) Mean densities (N/M²) by month of Cheumatopsyche petiti in 1981-82 and 1989-90. * = $p<0.05$; ** = $p<0.01$).

similar to those of the population densities for these species. Production rates of O. fastiditus and B. vagans were more than 300% and 200% greater, respectively, in 1989-90 than in 1981-82 (Fig. 2).

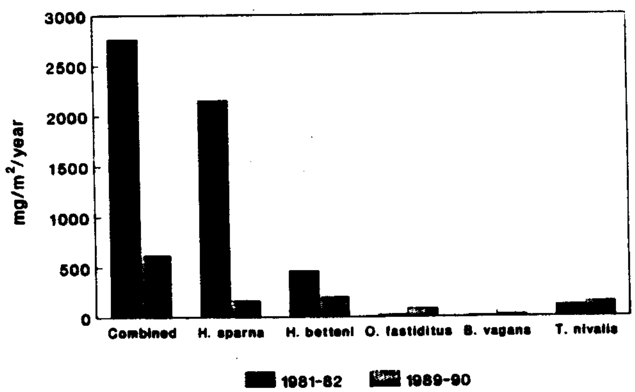


Figure 2. Combined (all 5 species) and individual species secondary production rates (mg/m²/yr) in 1981-82 and 1989-90.

Population densities of shredders showed mixed responses between years (Table 2). Mean annual densities of Amphinemura delosa (Ricker) and Tipula abdominalis (Say) were significantly lower in 1989-90 than in 1981-82, Mean annual densities of Taeniopteryx nivalis, on the other hand, increased significantly in 1989-90. However, the secondary production rate of T. nivalis was only 20% higher in 1989-90 (Fig. 2), because of a greater mean individual biomass in 1981-82.

The predator functional feeding group is not represented because the only predaceous invertebrates at this location besides flatworms were the filter-feeding hydropsychid caddisflies. The only obligate scraper, Glossosoma intermedium (Klapalek), had greater densities in 1981-82 than in 1989-90 (8.91/m² vs. 6.6/m²), but differences were not significant ($p=0.389$).

Three of the five species for which we

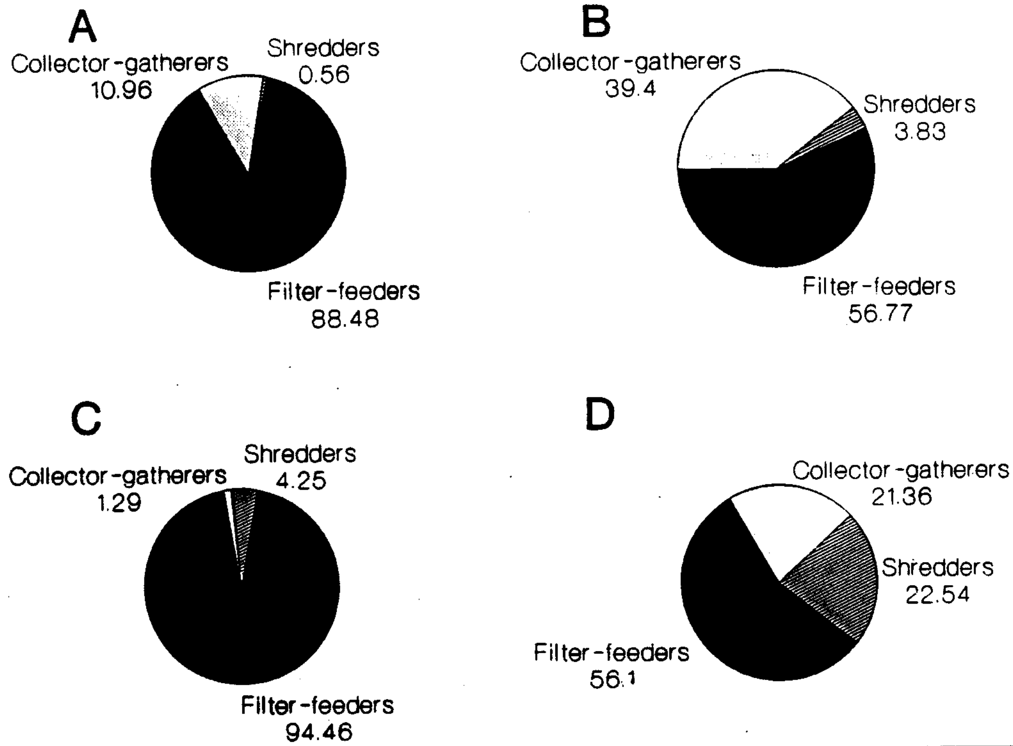


Figure 3. Percent contribution by functional feeding group to (A) 1981-1982 total densities, (B) 1989-90 total densities, (C) 1981-1982 secondary production rates, (D) 1989-90 secondary production rates. Relative values are calculated using only five species in Figure 2.

calculated secondary production rates had higher rates in 1989-90 compared to 1981-82. However, summing the production rates for all five species resulted in a substantial decline in production rates in 1989-90 compared to 1981-82 (Fig. 2). Of these five species, the two filter-feeders in 1981-82 contributed 88.48% of the numbers and 94.46% of the combined secondary production rate (Fig. 3). In 1989-90, these filter-feeders declined in both densities and production rates, resulting in a large decline in total secondary production rates. The three species that increased in production rate in 1989-90 versus 1981-82 were those that contributed little to total production rate. The result is a shift from a community dominated by filter-feeders in both numbers and production rate in 1981-82 to a community in 1989-90 in which collector-gatherers and shredders increased in importance in terms of relative contribution to both numbers and production (Fig. 3).

Discussion

It seems likely that the shift in invertebrate community structure and decreased secondary production rates observed in 1989-90 was the result of increased sediment deposition into the study area. Differences cannot be explained by changes in the physicochemical characteristics of Juday Creek between years (Table 1). Other authors have noted that reduction or elimination of the overhead canopy can result in abrupt changes in abundances of stream invertebrates (Behmer and Hawkins 1986, Newbold et al. 1980). However, the riparian vegetation in this part of the stream has remained undisturbed. Attributing differences between years to increased fish predation also is unsupported. Furthermore, data collected in 1985-86 showed that insect species abundances were similar to those from 1981-82 in this section of the stream (M.B. Berg, pers. comm.). The county drainage board began maintenance operations along Juday Creek soon after the 1985-86 study. Almost immediately, sediment deposition into the lower portion of Juday Creek increased substantially. The result has been severely reduced population densities for some species and higher densities for others.

Functional feeding group classification proved to be a good predictor of a species' population response to the sediment deposition. Filter-feeder population densities were the most severely reduced (Table 2, Figure 1). Reduction of filter-feeder densities due to greater sediment deposition is consistent with their biology and habitat requirements. These organisms require a solid and somewhat stable substrate on which to spin their nets (Hynes 1970, Minshall 1984), and are considered intolerant of heavily silted and sandy areas where they lose their attachment to the substrate (Marsh and Waters 1980, Tebo 1955). In addition, large amounts of suspended inorganic sediments can clog nets and interfere with the feeding mechanisms of the net-spinners (Nuttall and Bielby 1973). These results generally are consistent with those found in other studies. The net-spinning caddisfly Arctopsyche grandis (Banks) is highly sensitive to sedimentation due to the filling of interstitial spaces of rocks (Cline et al. 1982, McClelland and Brusven 1980). Barton (1977) found reduced densities of Hydropsyche slossonae Banks (48%) and Cheumatopsyche sp. (66%) in an Ontario stream immediately downstream from a highway construction site compared to upstream locations. He suggested that damage to benthos only occurs when stones are buried by sediment, which was the case in our study. Gurtz and Wallace (1986) and Benke et al. (1984) found lower production rates of net-spinning caddisflies on sand when compared with more stable substrates. Other studies also have found that filter-feeders are intolerant of sediment additions (Cherry et al. 1979, Nuttall and Bielby 1973, White and Gammon 1976).

In contrast to the filter-feeders, mean annual densities of all collector-gatherers increased significantly in 1989-90 from the 1981-82 levels (Table 2). Although most of the deposited sediment was inorganic sand during the 1989-90 study, the amount of organic material deposited in the riffle area probably increased as well. This would result in a greater food supply for the collector-gatherers, which forage along the substrate for food particles (Berkman et al. 1986, Merritt and Cummins 1984). Elmid beetles showed the greatest rise in numbers (Table 2). Although studies have shown that Optioservus and Stenelmis prefer larger, solid substrates (Cummins and Lauf 1969, Marsh and Waters 1980, Rabeni and Minshall 1977), these organisms are known to tolerate fine sediments to some extent (Brown 1987, White and Gammon 1976). The reason for the increased density of Macronychus glabratus in 1989-90 is unclear, since this species is almost always associated with wood substrate (Brown 1987, Hynes 1970). The amount of woody debris in the stream was not quantified in 1981-82 or in 1989-90. Stenonema also is somewhat tolerant of silt (Dance and Hynes 1980, Jones and Clark 1987), and could benefit from an increase in deposition of organic matter. Investigators have found that Baetis nymphs generally prefer larger substrates and drift in the presence of large quantities of sediment (Culp et al. 1986, Wagner 1989, White and Gammon 1976). However, numbers of the European species Baetis rhodani (Pictet) increase as sediment deposition increases (Nuttall and Bielby 1973, Scullion and Edwards 1980). Wallace and Gurtz (1986) found that although production rate of Baetis sp. was greatest on cobble and gravel, individuals of this genus were found in moderate numbers in sandy areas. Culp et al. (1986) showed that while sediment transport reduced B. tricaudatus Dodds densities by 67%, sediment deposition actually decreased drift rates of this species. As with the other collector-gatherers in this study, the potential increase in food material transported into the study area may have offset any negative effects on B. vagans associated with the loss of stable substrate. However, densities of O. fastiditus, Antocha sp., and Stenonema spp. all decreased substantially in April and May of 1990, coinciding with the sediment pulse that covered the study site. It is possible that continued heavy sediment deposition could eventually cause population declines in many of these collector-gatherers.

The population responses of the shredder functional feeding group varied depending on the species (Table 2). Taeniopteryx nivalis appeared to benefit from the increased sediment deposition. T. nivalis nymphs are generally found in leaf packs or other debris along the stream margins (Sephton and Hynes 1984, Stewart and Stark 1988). This species may not be affected by sediment that covers the cobble and gravel substrate as long as there are sufficient leaf packs in the stream. During this study, there were many leaf pack accumulations both in the main channel and along the margins and backwater areas. Like the collector-gatherers, T. nivalis may have benefitted from a potential increase in available detritus in the study area. Because adults emerge in February and the nymphs diapause deep in the substrate until September (Stewart and Stark 1988), this species would not have been affected by the sediment pulse that occurred in the spring. In contrast, Tipula abdominalis had significantly lower densities in 1989-90 compared to 1981-82 (Table 2). Cummins and Lauf (1969) found that Tipula caloptera Loew preferred coarse substrates, but showed a wide tolerance for finer sediments, including silt. They suggest that these larvae are probably found in microhabitats of finer sediments and organic material between and behind coarse sediments. If T. abdominalis has similar tolerances, then this species should be moderately affected by the increased deposition. Amphinemura delosa densities also were significantly lower in 1989-90 (Table 2). Another congeneric species, A. sulcicollis (Stephens), is known to move from leaves to stone as it develops (Hynes 1976). If A. delosa exhibits a similar habitat shift, then a reduction in numbers would be expected with increasing sediment deposition. However, Scullion and Edwards (1980) found that A. sulcicollis was tolerant to mine discharge siltation. The lack of tolerance of A. delosa in our study may represent species-specific differences in tolerance or may be related to the amount of material deposited.

Most studies that examine the effects of sediment deposition on benthic invertebrates look only at changes in population densities or relative changes in species composition (Barton 1977, Nuttall and Bielby 1973, Scullion and Edwards 1980). The few studies that have looked at changes in biomass found it to be a better measure of benthos response to sedimentation than density and diversity (Letterman and Mitsch 1978, Marsh and Waters 1980). We have found no studies that examine the effects of sediment deposition on the secondary production rates of stream invertebrates. Studies have compared invertebrate secondary production rates between logged and unlogged areas (eg. Wallace and Gurtz 1986), but have difficulty separating the relative effects of sediments, increased algal growth, and water temperatures.

There are many advantages to calculating secondary production rates rather than looking only at changes in abundances. Secondary production incorporates a measure of individual growth as well as population density, and provides a measure of the functional importance of a species to stream energy flow and nutrient processing (Short et al. 1987). From a management perspective, invertebrates are an important component of fish diets and may limit fish production (Benke 1984, Tebo 1955). Our results suggest that changes in secondary production rates between years give a clearer picture of what is happening to the benthos in Juday Creek than changes in abundance. Because eight species show greater densities in 1989-90 compared to six species with greater densities in 1981-82, examination of numbers alone suggests that the only impact of the sediment on the invertebrate community was a change in relative abundance of species. However, the species that had reduced densities in 1989-90 are those that contributed the most to invertebrate secondary production rates in 1981-82. Those that had increased densities in 1989-90 contributed little to secondary production in 1981-82 (Figure 2). The result was that the combined production rates for five species decreased from 2765.1 mg/m^2/year in 1981-82 to 653.8 mg/m^2/year in 1989-90. This 78% reduction in secondary production rate represents a substantial decline in the amount of food available to support higher trophic level organisms such as fish. The response of Taeniopteryx nivalis populations also represents a good example of the value of calculating production rates. While densities of this species increased approximately 6 times in 1989-90 from 1981-82, production rates increased only 20% (Fig. 2). The large increase in mean densities of this species was mostly offset by lower individual growth rates.

Our results suggest that a functional feeding group classification of organisms offers a method for predicting the downstream impacts of stream maintenance activities. If a community is dominated by filter-feeders, then substantial impacts associated with an increase in sediment deposition may be expected. If collector-gatherers contribute the majority of invertebrate production, then moderate increases in sediment transport and deposition may actually enhance population densities and production rates through increased import of organic material. However, heavy, sustained sediment deposition will probably have a negative impact on many of these species as well. In addition, secondary production rates are a better measure of invertebrate community response than diversity and population density. Finally, many studies have documented that the benthos recovers rapidly when the source of sediment is eliminated and high flows are allowed to wash the sediment downstream (Barton 1977, Cherry et al. 1979, Tebo 1955). If silt traps are properly maintained and cleaned out before filling with sediment, then it is possible that negative impacts associated with instream maintenance operations can be reduced.

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